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STATE OF WASHINGTON

DEPARTMENT OF ECOLOGY

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MEMORANDUM

May 28, 1981

To: Dick Cunningham

DC JAD

From: Dale Clark and Tim Determan

Subject: Burley Lagoon Water Quality Survey, August 1980

INTRODUCTION

During August 25 to 27, 1980, a water quality survey was conducted in Burley Lagoon and the surrounding drainage basin located near Purdy on the Kitsap Peninsula. The survey was carried out in response to recommendations from a previous survey conducted by the Department of Ecology (DOE) Southwest Regional Office (Anderson, 1980). The survey included sampling in the lagoon, all creek mouths, and upstream on the two major creeks found in the drainage. The major thrust was to update the previous study and further identify water quality problems in the lagoon during later summer. Fecal coliform contamination was the major factor investigated.

Fecal coliform (FC) bacteria are found in the intestinal tract of all warmblooded animals and are excreted along with fecal waste material. FC bacteria are capable of surviving in streams, rivers, lakes, estuaries, and other bodies of water for a long period of time and are useful in evaluating the extent of contact between fecal material and a receiving water. Due to the positive correlation of FC bacteria to fecal matter, it is reasonable to assume that when the bacteria are present in a water sample at a sufficiently high level, that the sample is contaminated by fecal material from a warmblooded animal including domestic or wild animals, or humans. The method of transport for this material may include: (1) failed or damaged septic systems or drainfields that can act indirectly (groundwater leaching or runoff) or directly (point-source input) as a link between human activity and receiving water; (2) access to receiving waters by domestic livestock either directly by lack of fencing or other protection, or indirectly through the leaching of groundwater that creates a condition in which contamination may occur; or (3) contamination created by direct contact that results from habitat and behavior characteristics of waterfowl and other wild animals.

Methods for determining the presence and concentration of FC are available in the text *Standard Methods for the Examination of Water and Wastewater* (1977). Once determined, these values can then be used to assess the degree of contamination and in certain instances, whether the source is human or non-human. Steps may then be taken to reduce or eliminate the source(s).

DESCRIPTION OF THE STUDY AREA

Burley Lagoon is located at the head of Carr Inlet in Henderson Bay. A long sand spit protects the lagoon from rough water. Salt water exchange takes place at a break in the spit at the southeast end of the lagoon (Figure 1). The lagoon flushes almost totally twice daily due to tidal motion. The lagoon is two miles long and one quarter mile wide, surface area is 370 acres, and the total volume has been estimated at 1.9×10^8 cubic feet (Kelley, 1963). The upper reach is characterized by a shallow, muddy bottom which gradually changes to a sandy, gravel bottom in the middle and lower reaches. The deepest point, located at the southern end, is 31 feet at high tide. Oyster growing has historically taken place in the middle and lower reaches of the lagoon. Two creeks, Burley and Purdy, supply most of the freshwater input, with small spring-fed brooks and runoff accounting for the remainder. Purdy Creek empties near the mouth of the lagoon while Burley Creek enters at the upper end. The middle and lower reaches of the lagoon are located in Pierce County. The upper reach and most of Burley and Purdy creeks are located in Kitsap County. Recreational and year-round housing are located all around the lagoon. The highest density of housing is found near the lower end. A small shopping center also is located there.

DESCRIPTION OF PROBLEM

Burley Lagoon is designated as a Class AA marine water which includes commercial harvesting of oysters as a protected beneficial use. The lagoon has shown high levels of fecal coliforms in water and sediment during recent history. Bacterial levels many times state Class AA standards have been found during water quality surveys of the lagoon (Cox, 1978; Thielen, 1979; Anderson, 1980). The Department of Social and Health Services (DSHS) has closed the middle portion of the estuary to commercial oyster harvesting due to high fecal counts (Figure 1).

A summary of previous work performed relative to fecal coliform contamination in Burley Lagoon is presented here:

- In August 1978, DSHS conducted a survey of Burley Lagoon, Purdy Creek, and Burley Creek after oyster tissue samples displayed fecal counts exceeding the market standard. The survey findings indicated that fecal counts were exceeding state AA water and oyster tissue standards in many parts of the bay. Final closure of the upper section of Burley Lagoon to oyster production occurred in September 1978 after detection of fecal coliform levels 700 times the state market standard (Figure 1) (Cox, 1978).

- In conjunction with the water quality survey, DSHS performed a door-to-door survey for the purpose of finding point sources of fecal contamination. A large number of failing septic systems were found along with other sources (livestock, waterfowl, domestic pets, etc.) (Cox, 1978). However, DSHS did not feel that these sources were accountable for the high levels displayed by the oysters (Thielen, 1979).

- DSHS wrote a letter to Pierce County Health Department requesting that pollution sources identified during the sanitary survey be corrected (Hays, 1978).

- In March 1979, DOE conducted a water quality survey which showed fecal coliform levels exceeding the state's water quality standard at all ten stations sampled in the lagoon. However, oyster tissue samples were also analyzed and found to be within the market standard (Thielen, 1979).

- In November 1979, a letter from the Tacoma-Pierce County Health Department to DSHS informed them that enforcement action had taken place on identified sewage disposal failures as per the August 1978 survey (Oliver, 1979).

- In March 1980, DSHS conducted a second shellfish tissue analysis for fecal coliforms. The results indicated that fecal coliform counts still exceeded the state market standard. In addition, DOE conducted a second water quality survey with results that demonstrated low fecal coliform levels at all sampling sites except station 1 (located below a pond where waterfowl are kept, presently Station 5, see Figure 1). The variability of the non-point sources was noted and a follow-up survey in the low-flow, warm-weather months was recommended (Anderson, 1980).

PURPOSE AND OBJECTIVES

Two objectives were to be accomplished by the survey. One objective was to measure water quality in the lagoon and creeks during the sampling period, with emphasis on fecal coliform bacteria. The other objective was to determine if significant changes in coliform levels have occurred since past surveys and subsequent repair of point sources.

METHODS

Sampling was conducted on three consecutive days during summer low-flow conditions. The sampling was designed with tidal conditions in mind since several stations in the upper lagoon could not be reached by boat during low tide.

Nine sampling stations were established in the lagoon and nine additional stations were set up in Burley Creek, Purdy Creek, and their tributaries. In addition, four sediment sampling stations were established in the lagoon. All of the lagoon stations were located at approximately the same sites used by Thielen (1979).

Six parameters were measured at each station: fecal coliforms (col./100 ml); dissolved oxygen (Winkler method); pH (S.U.); temperature (°C); specific conductance (umhos/cm); and salinity (o/oo). Stream flow data were collected with a Marsh McBirney flow meter (CFS). Additional parameters were measured at selected creek stations including nutrients; (NO_3-N, NO_2-N, NH_3-N, mg/L) and phosphates (T-PO_4-P, O-PO_4-P, mg/L); biochemical oxygen demand (BOD); chemical oxygen demand (COD); fecal coliform; and fecal streptococcus. A ratio of fecal coliform:fecal strep also was calculated.

Both water and sediment were collected for fecal coliform analysis at selected lagoon stations. Water samples were collected in sterile fecal coliform bottles while the sediment samples were collected using a sterile scoop and whirl-pacs. Oyster tissue samples were not collected due to non-availability of laboratory services. The membrane filter test (MF) was used in analyzing coliform levels in water whereas the most probable number test (MPN) was used in analyzing coliform levels in sediments. MPN was used in coliform analysis of sediments because sediments can interfere with the membrane filter test. Whenever possible, the membrane filter test was used because of greater accuracy and precision (Nancy Jensen, personal communication, 1981).

RESULTS

Tables 1 through 3 summarize data collected during this survey.

Among the streams and in the lagoon, dissolved oxygen, temperature, and pH all were generally within the specified limits for Washington State Class AA (extraordinary) waters, as defined in the Department of Ecology laws and regulations manual (1977) (WAC 173-201-045) and listed in the following text:

1. <u>Dissolved Oxygen</u>

   a. Freshwater - shall exceed 9.5 mg/L.

b. Marine - shall exceed 7.0 mg/L except when the natural phenomenon of upwelling occurs, natural dissolved oxygen levels can be degraded by up to 0.2 mg/L by man-caused activities.

2. Temperature

a. Freshwater - water temperature shall not exceed 16.0° Celsius due to human activities.

b. Marine - water temperature shall not exceed 13° Celsius due to human activities.

3. pH

a. Freshwater - shall be within the range of 6.5 to 8.5 with a man-caused variation within a range of less than 0.2 units.

b. Marine - shall be within the range of 7.0 to 8.5 with a man-caused variation within a range of less than 0.2 units.

Refer to Tables 1 and 2 for a summary of data relating to these parameters collected during the survey.

Fecal coliform values exceeded the state standard in Burley Lagoon and five of the seven streams surveyed (Table 3). The creeks included: McCormick Creek (Station 2); Purdy Creek (Station 3); Burley Creek (Station 4); unnamed creek (Station 6); and unnamed creek (Station 7).

Hyde Creek (Station 1), and unnamed creek (Station 5), were within the standard for fecal coliform.

The fecal coliform standard as defined in the laws and regulations manuals (DOE, 1977) is included in the following text:

Fecal Coliform Organisms

a. Freshwater - shall not exceed a median value of 50 organisms/100 ml with not more than 10 percent of samples exceeding 100 organisms/100 ml.

b. Marine - shall not exceed a median value of 14 organisms with not more than 10 percent of samples exceeding 43 organisms/100 ml.

In order to determine the status of Burley Lagoon in relation to the Water Quality Standards, two approaches were used. First, the results of all stations and times were pooled. In the second approach, each individual station was considered.

In the first case, Burley Lagoon results were based on 30 samples collected over three days on varying tides at 14 stations (station numbers 8 through 17 inclusive and A through D, inclusive). The range was from less than 1 to 100, with a median value of 6 FC organisms per 100 ml (Table 1). Thirteen percent of the samples exceeded 43 FC/100 ml thereby exceeding the 10 percent limit found in the standard (Table 3). The values suggest that during the survey water quality in Burley Lagoon was very close to meeting the state water quality standard. The geometric mean for the samples was 5.92; with a variance of 4.14, these values compare very favorably with the median and increase confidence in the results. Geometric means were compared among the stations (Table 1). There did not appear to be any areas within the lagoon that displayed values substantially higher than others. This may indicate that non-point sources within the lagoon and associated drainage area that created areas of high FC concentration such as the drainfields, concentrations of domestic waterfowl cited by Thielen (1979) and Anderson (1980) may no longer exist and that the remaining contamination sources may be Purdy and Burley creeks.

In the second case, Table 1 shows circled median FC values for each station sampled during this survey. Out of nine Burley Lagoon stations (stations 9 through 17), one had a median value in excess of the standard (Station 11) with one out of three (33 percent) of the samples exceeding 43 FC per 100 ml. Three other stations (14, 15, and 16) had acceptable median values, but each had one out of three values exceeding an allowable 43 FC per 100 ml.

Both Burley Creek and Purdy Creek were intensively surveyed on August 26, 1980. The two streams accounted for 80 percent and 10 percent, respectively, of all freshwater input from streams entering the lagoon (Table 5). The parameters dissolved oxygen (mg/L), temperature (°C), and pH (S.U.) all were within state water quality standards for Class AA freshwater. All nutrients (phosphates, nitrite, nitrate, and ammonia (NH_3-N) were within limits considered protective of Class AA fresh and marine waters from excessive algae growth and eutrophication. In addition, biochemical oxygen demand (BOD) and chemical oxygen demand (COD) were analyzed to determine if oxygen depletion was a problem in the creeks. Both values were within limits considered safe for Class AA freshwater (Table 2).

In Purdy Creek, five stations exceeded the state water quality FC standard for Class AA waters. These included Stations 3, 3-1, 3-2, 3-3, and 3-4.

Wikstein Creek (3-A), a tributary of Purdy Creek, and station 3-5 were within the standard for FC.

All of the stations on Burley Creek exceeded the water quality standard.

Fecal coliform loading for each creek was calculated using stream flow and the three-day mean of the FC concentration (Table 5).

Purdy and Burley creeks acounted for 32 percent and 61 percent, respectively, of the total FC load from creek input indicating that 93 percent of all FC contamination from freshwater sources came from those two creeks.

Fecal streptococci (FS) bacteria also were analyzed for and fecal coliform, fecal streptococcus ratios (FC:FS) were determined to aid in predicting sources of contamination for the two creeks.

Some background information is appropriate to understand the significance of the FC:FS ratio. Both fecal coliform and fecal streptococcus are found in the intestinal flora of warmblooded animals. Previous research groups have determined that humans and domestic animals have different ratios of FC:FS. Ratios with a value exceeding 4 are considered to be from human sources, while ratios less than 0.7 are from animals (Geldreich, 1966; Geldreich and Kenner, 1969; Geldreich, et al., 1968). FC:FS ratios from water samples also have the same characteristics and are used to determine whether contamination is human or non-human. Ratios between the two extremes result in uncertain conclusions concerning sources of contamination.

A major weakness in using the FC:FS ratio is that after 24 hours from the time of excretion and discharge into a receiving water, the bacteria begin to die off at different rates. The die-off differential changes the ratio, therefore the ratio is no longer representative of that found in fresh fecal matter (Feachem, 1975). It is therefore recommended that the FC:FS ratio only be considered valid for 24 hours after excretion and subsequent discharge. In the field, this ideal situation seldom is achieved due to the variability common to a natural environment. Run-off, retention time, and other factors would delay the time of discharge during which the bacteria would have already gone through a period of die-off. However, there is another factor that allows FC:FS ratios to be used for in-field evaluation. This factor does not require previous knowledge of coliform age or field retention time and is based on the discrepancy between survival rates for various types of coliform bacteria. McFetters, et al. (1974) discovered that Enterococci, the dominant fecal streptococcus group in humans, survive longer in the stream environment than fecal coliform bacteria which survive longer than the FS group common to cattle, S. bovis, which in turn have a higher survival rate than S. equinis, common to horses. This means that the FC:FS ratios will vary differently in humans than domestic animals over time. The following table summarizes the human and non-human FC:FS ratio characteristics (Table 4):

Table 4[1]. Fecal Source Related to FC:FS Ratios.

Initial FC:FS Ratios	Change Through Time	Probable Source
>4	rise	uncertain
	fall	human
<0.7	rise	non-human
	fall	uncertain

[1]From Feachem (1975)

Coinciding with the changes in FC:FS ratios, Feachem (1975) suggested that declining bacteria concentrations at stations sampled downstream from the initial sampling point indicate humans as the most probable source of contamination. It is unclear from his article what would happen to the bacterial concentrations from domestic animal sources. It is assumed that they also would decline at downstream sampling sites. Feachem did not indicate if other inputs that occur downstream from the initial source could be taken into account by the FC:FS ratio analysis. However, it is felt that as a first step in predicting contamination sources, the FC:FS ratio should be considered a useful analytical tool.

Referring to Table 2, FC:FS are tabulated from Burley and Purdy creek intensive surveys. The ratios are calculated from a single sample per station and not statistically valid for predicting stream bacteria populations. However, each stream does appear to display unique characteristics similar to those described in the previous discussion of FC:FS ratios. Purdy Creek displays higher FC:FS values (greater than 4) upstream that generally tend to drop off at downstream stations; a pattern characteristic of human contamination. Burley Creek displays low values (less than 0.7) at downstream stations, with uncertain values from the upstream and middle stations (less than 4; greater than 0.7), indicating contamination from mixed sources, both human and animal.

Bacterial concentrations are highly variable for all of the stations on Purdy Creek. This variability suggests that the contamination sources may be irregular in nature and originate from many sources along the stream (i.e., failed drainfields). Burley Creek concentrations display less variation, suggesting a more continuous and regular source of contamination, possibly from domestic animals pastured adjacent to the stream.

In conclusion, the data from the intensive surveys of Burley and Purdy creeks suggest that contamination sources are different for each creek. Purdy Creek appears to have more human contamination, while Burley Creek data suggest domestic animal contamination. This appears to correspond with land use observed during the study.

DISCUSSION

Fecal Coliform Standards in Shellfish

From the previous section, it appears that some discussion of the requirements for shellfish sanitation would be appropriate. Burley Lagoon is classified as AA (extraordinary) marine waters which include shellfish harvesting as a protected beneficial use.

The DSHS criterion for oyster harvesting is adapted from the National Shellfish Sanitation Program (U.S. Health, Education and Welfare, 1965) which classifies oysters with FC densities not to exceed 230 organisms per 100 grams of tissue (FC/100 g) as fit for human consumption. Fecal coliform concentrations that exceed these levels result in conditional sampling which may result in closure to harvesting. The standard is applicable to harvested oysters and oysters still in their habitat. Sanitary surveys are routinely conducted to evaluate the sanitary condition of commercial oyster beds.

It has been determined that shellfish have the ability to filter and concentrate bacteria to levels many times that found in the surrounding waters. Vasconcelos, et al. (1969) studied bacteria accumulation and elimination response of Pacific oysters (*Crossostrea gigas*) in experiments conducted over a one-year period in Northwest marine waters. The annual mean ratio for accumulation was 21 times the bacterial (FC) concentration found in the surrounding water. The study also stated that accumulation of bacteria is influenced by two environmental factors: (1) amount of rainfall; and (2) temperature. High rainfall increases terrestrial runoff and elevates FC levels in the marine waters. Warmer water temperatures increase metabolic activity and filtration in the oysters. Since high runoff is associated with colder winter temperatures, and warm temperatures are associated with seasons that normally have low runoff, there exists at least two opposing factors in determining FC concentrations in oyster tissue and surrounding waters. Therefore, it appears that the correlation between concentrations of FC in water and FC in oyster tissue is highly variable and is based on complex interactions between the oyster and its surrounding environment.

Table 6 represents accumulation ratios for Pacific oysters and illustrates the correlation between temperature, rainfall, and FC concentration in oysters. It is noteworthy that the highest count occurred in March (1966) when precipitation was high and water temperatures were low. Similar temperatures and precipitation existed in January (1966) yet FC counts were extremely low, possibly indicating other factors such as oyster life cycles may contribute to oyster FC concentrations.

Based on Vasconcelos' findings, under average environmental conditions, oysters could concentrate 14 FC/100 ml (state AA water standard) 21 times to 294 FC/100 g in oyster tissue, thereby violating the state market standard of 230 FC/100 g oyster tissue. This suggests that the state standard for water quality for fecal coliforms may not be adequate to protect oyster marketability and may require re-evaluation to determine levels of FC concentration in the water that would provide adequate protection for harvesting of oysters.

Comparison of Burley Lagoon Results with Previous Surveys

Comparison of results was carried out between this survey and the DOE March 1979 and March 1980 surveys. Differences in analytical methods could account for some difference among surveys. Samples taken in August 1978 and March 1979 were analyzed by the MPN (most probable number) method. The MF (membrane filter) method was applied to samples from later surveys. Some controversy exists as to the comparability of MF to MPN results. However, it is assumed for this data review that analytical differences between laboratories and methods were not important.

Comparison of results was carried out by applying a test of equality of means of two sets of samples whose variances are assumed to be unequal (Sokal and Rohlf, 1969). FC data were transformed by changing the values to base-10 logarithms for use in this section. This type of transformation is commonly applied to fecal coliform data in order to correct the highly variable, non-normal data into a form more appropriate for parametric statistical comparisons. In addition, comparisons were made only where the same stations were sampled during each sampling period. In most cases, consistent sampling patterns were not employed in the past. A summary of these data is shown in Table 7. These comparisons should be regarded as tentative, since data available for comparisons are limited.

FC levels in the water may be strongly associated with tide. Pooled Burley Lagoon results for March 1979 and March 1980 suggest this association. The 1980 average (high slack) is significantly lower than that of 1979 (low slack) (t'_s = 8.55; P = .05; df = 7,8 one-tailed). Similarly, Burley Lagoon data on August 25, 1980 (high slack) are lower in average than those of August 27 (mean height, dropping) (t'_s = 5.58; P = .05, df = 8,7; one-tailed). Thus, there may be a strong negative correlation of tide height and FC values in water.

If we examine the freshwater sources feeding the lagoon, we find little evidence of improvement in water quality. Burley Creek results in August 1978 and August 1980 are not significantly different (t'_s = .34, P = .05; df = 3,5, two-tailed), nor are Purdy Creek results for the same period (t'_s = 0.78; P = .05; df = 2,2; two-tailed). Data from the other freshwater inputs are insufficient to perform statistical tests. An inspection of means between dates for each creek suggests little difference.

Potential Sources of Contamination

Correction of septic tank drainfield problems as recommended by DSHS (Cox, 1979) and carried out by Pierce County Health Department (Oliver, 1979) does not appear to have made an effective impact on FC levels in Burley Creek, Purdy, and other drainages. This suggests that the health department actions were not effective in correcting the sources of poor water quality found in the majority of creeks feeding Burley Lagoon.

Stream loading of fecal coliforms was calculated based on samples collected over three days (Table 5). The results show that Burley and Purdy creeks produced 93 percent of the total fecal coliform input from the freshwater sources. Burley Creek had greatest impact with 61 percent, while Purdy Creek produced 32 percent. The other streams accounted for only 7 percent, indicating that future investigations on freshwater inputs to the lagoon should concentrate on Burley and Purdy creeks.

There may exist a natural background level of bacteria in some areas of the embayment that should be considered. During breeding season, protected habitats such as Burley Lagoon are selected by sea birds and other wild fowl as areas of nesting. The upper reaches of the lagoon contain many areas of natural habitat that attract birds. During the survey, there was little evidence of a wildfowl population large enough to create an FC problem within the lagoon; however, such populations would be seasonal and therefore may not have been present during the time of year the survey took place. A large population of wildlife can add tremendously to fecal coliform input. A single duck can contribute as much contamination as three humans (Bernhardt and Yake, 1979). At present, little is known about the impact of this coliform source. Future investigations should address this aspect of the problem.

In addition to the freshwater loads and the role of residential and migratory bird populations, it is possible that incoming Henderson Bay waters may be a significant load. Kelley (1963) estimated that the volume of Burley Lagoon (1.9×10^8 cubic feet) is flushed almost totally twice a day. Each day, therefore, 3.8×10^8 cubic feet of Henderson Bay enters Burley Lagoon. During the same period, the total input of freshwater from Burley and Purdy creeks is 6.84×10^5 cubic feet or 1/600 the amount of marine input.

Very limited FC data recorded at Station 17 (outside the mouth of Burley Lagoon) suggest that FC levels in incoming water was about 5 FC per 100 ml, a little high for Puget Sound waters in general. This value gives a calculated incoming load of 5.4×10^{11} FC per day or over three times the total input from Burley and Purdy creeks. However, this incoming load is probably removed when the dropping tide drains the lagoon. Although Henderson Bay water may play a significant role in the total mass balance of FC loading to Burley Lagoon, there are indications that

FC levels are higher on the outgoing tide than on the incoming tide. This suggests that the freshwater input is indeed the major contributor to lagoon contamination. This conclusion is based on very limited data, however, and the determination of the relative importance of Henderson Inlet versus freshwater sources requires further study.

CONCLUSIONS

1. Fecal coliform levels continue to slightly exceed state water quality standards (but are very close to the standards) for state AA shellfish growing waters.

2. Comparison of fecal coliform results suggests a strong negative correlation with tide height within Burley Lagoon.

3. The sanitary survey and subsequent actions by the Pierce County Health Department does not appear to have had a demonstratable effect on water quality of Burley and Purdy creeks.

4. Water quality standards may not adequately protect oyster growing areas because of concentration of fecal coliforms in tissue and effects of physical factors such as temperature, runoff, and tide height.

5. This study indicates the relative importance of individual sources is still unknown.

6. The stream loading study points to Burley and Purdy creek areas as the possible major sources of fecal coliforms.

7. Non-point sources around the lagoon and incoming Henderson Bay waters are other possible sources which need further documentation in order to determine the relative importance of the two creeks.

RECOMMENDATIONS

Past studies have identified several sources of the contamination in Burley Lagoon -- failing wastewater systems, agricultural wastes, and waterfowl. However, the relative importance of each source has not been evaluated. Some work has been done to determine general circulation patterns within Burley Lagoon, but studies to determine the fate of fecal bacterial inputs have not been performed. Several issues must be evaluated before any cause-and-effect relationships can be determined. These issues and a research need for each issue follow:

Issue One - What is the relative contribution of each contamination source into Burley Lagoon -- human or agricultural? It is essential to evaluate this question in order to develop management practices or structural features that are rational and cost-effective.

Research Need - Research should be confined to Burley and Purdy creeks since these streams contribute over 90 percent of the contaminant load into Burley Lagoon. Four sets of observations should be made during wet and dry seasons respectively in order to provide sufficient data to calculate significant differences between locations and seasons. Existing stations could be used since they are located at critical land-use boundaries. Replicate samples from each station could be analyzed for FC and FS in order to calculate ratios to determine the contamination sources as human or non-human. Stream flows should be measured with a flow meter at each station in order to quantify loads from each land-use type. It will be necessary to perform a time-of-travel study using fluorescent dye on each stream because FC and FS bacteria die off in the environment at different rates. As an adjunct, observations of dye concentrations over time by flourometer analysis can be used to estimate stream flow and provide a check on the method using a flow meter.

Issue Two - How are contaminated stream waters mixed with the receiving waters of Burley Lagoon?

Research Need - In order to evaluate this question, Rhodamine WT dye can be continuously injected into Burley and Purdy creeks and samples taken from each creek mouth above tidal influence. Additionally, a three-dimensional sampling grid can be set up in Burley Lagoon and sampled several times during a complete tidal cycle. Samples can be analyzed for dye and fecal coliforms. Mixing and dilution rates can thus be estimated and tidal circulation within the lagoon mapped. Correlation analysis of dye concentrations by flourometer and fecal coliform concentrations (MF) might provide insight into sources of contamination. In the absence of any factor but dilution, there should be strong 1:1 positive correlation between dye and bacteria densities. Departures from 1:1 correspondence could be indicative of changes in coliform density for reasons other than dilution. Higher coliform levels relative to dye concentration may be due to mixing of stream waters input with FC derived from sediments agitated by tidal flow. A higher FC:dye ratio may also be due to mixing with previously contaminated tidal exchange. A lower ratio may be due to bacterial die-off. Departures from expected values could be tested for significance using statistical analysis. Net changes could be inferred.

Issue Three - How do physical factors such as sediment disturbance by tidal currents or inflow of contamination from tidal exchange affect levels of bacteria in Burley Lagoon?

Research Need - The role of contamination by water returning to the lagoon from previous tide stages could be evaluated by establishment of a cross-sectional grid across the entrance to Burley Lagoon. Quantification of incoming and outgoing flows could be estimated using drogues, dye, or current meters and a mass-transport budget for the lagoon determined. These values in conjunction with periodic bacteria samples over a complete tide cycle, could be used to estimate bacterial loads entering and leaving Burley Lagoon. These loads could be compared to load inputs from Burley and Purdy creeks. Dye release in conjunction with this effort could be used to estimate tidal exchange. In order to evaluate the issue of release of bacteria from disturbed sediments, an experiment could be conducted in which a number of plexiglass boxes or aquaria could be placed carefully on the sediments. Initial sets of samples could be extracted from the boxes using a syringe or hand vacuum pump. The entrapped water could then be circulated using submersible bilge pumps of such capacity as to approximate tidal transport across the bottom at that point. More samples could be extracted over time during the pump cycle to determine changes in bacterial densities due to the induced current.

Issue Four - What role do transient bird populations play in bacterial contamination of Burley Lagoon?

Research Need - In order to evaluate this issue, a census of bird species and numbers could be conducted in association with high-slack tide sampling of Burley Lagoon waters for FC and FS levels. Samples from Burley and Purdy creeks immediately upstream from tidal influence should be taken for comparison. This work should be done monthly in order to provide meaningful association between population sizes, bacterial levels, and FC:FS ratios.

In addition to specific issues, several other tasks should be performed in conjunction with the other research tasks:

1. Carry on monthly routine physical/chemical and bacteriological measurements at selected stations in Burley Lagoon and Burley and Purdy creeks' mouths. Temperature, turbidity (secchi and NTU), D.O., and salinity are of special interest. This would be continued for one year.

2. Survey and document all areas within the Burley and Purdy creek basins that provide access of livestock to creeks and streams.

3. Coordinate a sanitary survey with Kitsap and Pierce county health agencies in order to update past efforts and identify new and continuing problems.

The research program that has been outlined will incur some measure of cost in terms of time, materials, and equipment. The costs of these efforts and appropriate corrective measures must be viewed in terms of the potential for improved water quality and increased marketability of oysters in Burley Lagoon. If land use within the Burley Lagoon watershed continues to intensify, it is possible that conditions may never allow marketability of oysters. In fact, the research effort we expend may not be adequate to assure DSHS approval to market oysters grown in those zones currently closed to harvest. We therefore recommend that these questions be considered by upper management prior to commencement of further planning or study.

DC:TAD:cp

Attachments

cc: Jim Krull

LITERATURE CITED

American Public Health Association, Inc., et al., 1970. *Recommended Procedures for the Examination of Seawater and Shellfish,* New York, N.Y., 4th Edition

American Public Health Association, 1975. *Standard Methods for the Examination of Water and Wastewater,* Am. Water Works Assoc., Water Pol. Control Federation, 14th Edition

Anderson D., 1980. Follow-up Report - Burley Lagoon, DOE Memo. Bacteriological Survey

Bernhardt, J. and W.E. Yake, 1979. *Assessment of Wastewater Treatment and Receiving Water Quality - South Fork of the Palouse River at Pullman, Washington.* Dept. Ecology Project Report 5, 46 pp.

Clark, D., 1980. Summary of Burley Lagoon Survey Activities, DOE memo.

Cox, F., 1978. *Sanitary Survey of Burley Lagoon, Burley Creek, and Purdy Creek.*

Feachem, R.G.A., 1974. Fecal coliforms and fecal streptococci in streams in the New Guinea highlands, *Water Resources 8,* pp. 367-374.

Feachem, R., 1975. An improved role for fecal coliform to fecal streptococci ratios in the differentiation between human and non-human pollution sources, *Water Research Vol. 9,* Pergamon Press, pp. 689-690.

Geldreich, E.E., 1966. *Sanitary Significance of Fecal Coliforms in the Environment,* Water Pol. Control Res. Svc. Pub. No. WP-20-3, U.S. Dept. of Interior, 122 pp.

Geldreich, E.E., L.C. Best, B.A. Kenner, and D.J. Van Dunsel, 1968. The bacteriological aspects of stormwater pollution. *Journ. of Water Pol. Control Fed. 40,* pp. 1861-1872.

Geldreich, E.E. and B.A. Kenner, 1969. Concepts of faecal streptococci in stream pollution, *Journ. of Water Pol. Control Fed. 41,* R336-R352.

Hays, M., 1978. Letter to Tacoma-Pierce County Health Dept., Walter R. Herron, M.D., MPH, Attn: Donald Oliver, Director of Environmental Health.

Jensen, N., 1981. Microbiologist, Wash. State Dept. Ecology, personal communication.

Kelley, P.S., 1963. *Brief Hydrographic Survey of Burley Lagoon, Washington.* Northwest Shellfish Sanitation Laboratory

McFetters, G.A., G.K. Bissonnette, J.J. Jezeski, C.A. Thomson, and D.G. Stuart, 1974. Comparative survival of indicator bacteria and enteric pathogens in well waters, *Applied Microbiology 27,* pp. 823-829.

Oliver, D., 1979. Letter to Food and Housing Section, Health Services Div., Wash. State Dept. Social and Health Svcs, Mr. Max Hays, Director.

Sokal, R.R. and T.J. Rohlf, 1969. *Biometry,* W.H. Freeman and Co., San Francisco CA, 776 pp.

Thielen, J., 1979. Burley Lagoon Bacteriological Survey, DOE memo.

U.S. Public Health Service, 1965. *National Shellfish Sanitation Program: Part I: Sanitation of Shellfish Growing Areas,* Dept. of Health, Education and Welfare.

Vasconcelos, G.J., W. Jakubowski, and T.H. Erickson, 1969. *Bacteriological Changes in Shellfish Maintained in an Estuarine Environment.* 1968. Proceedings, Nat'l Shellfisheries Assoc., v. 59, 17 pp.

Washington State Department of Ecology, 1977. *Washington State Water Quality Standards.*

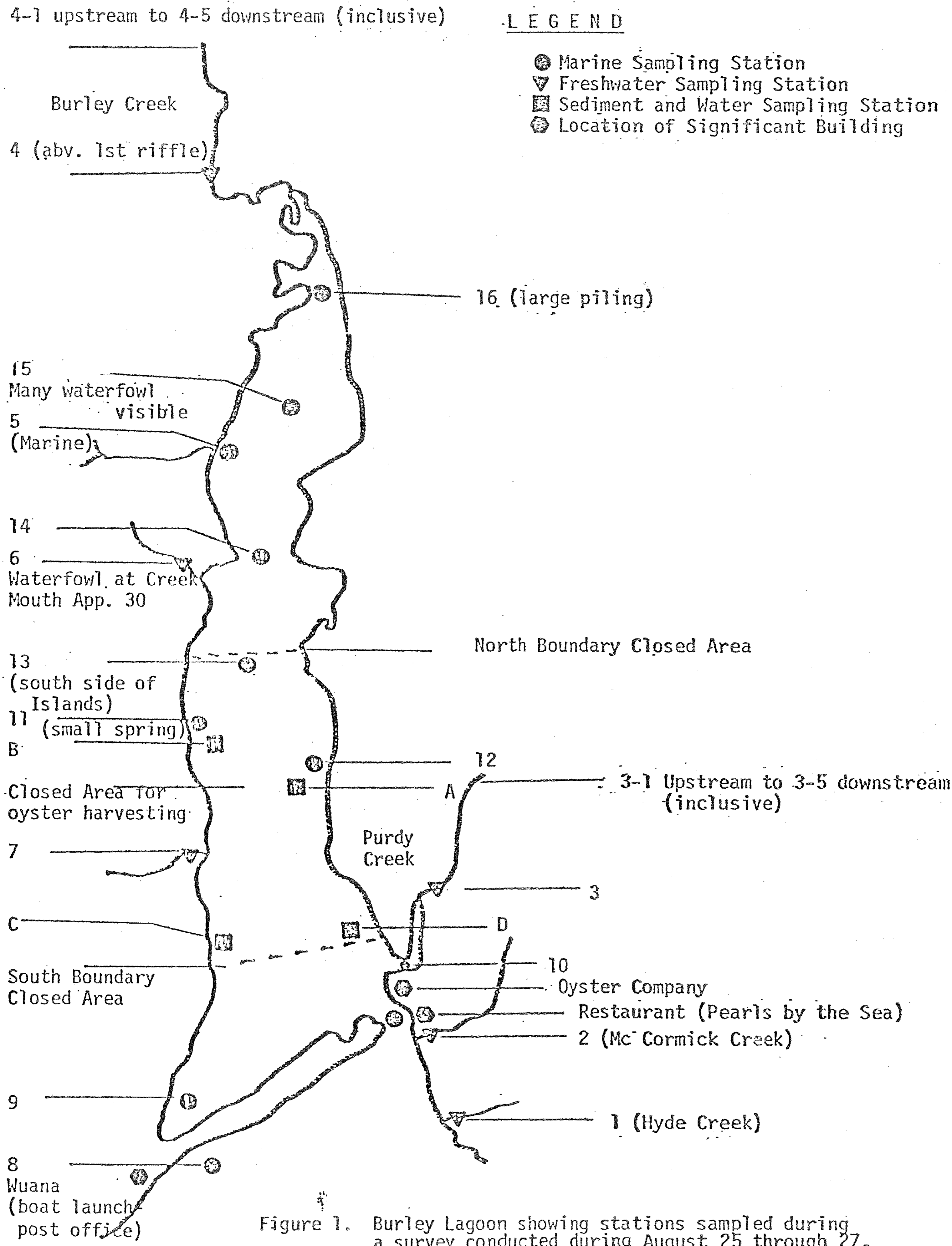

Figure 1. Burley Lagoon showing stations sampled during a survey conducted during August 25 through 27, 1980.

Table 1. Partial Summary of DOE water quality data from August 1980 survey.

Station (Ref.)	Description	Date	Fecal Coliforms[1] Org/100 ml	Geometric Mean	Conductivity (umhos/cm)	Dissolved Oxygen (mg/l)	pH	Temp. (°C)
1	Hyde Creek - 20 yds. upstream from mouth	8/25	25		131	10.2	7.6	15.2
		8/26	35	27.20	183	10.6	7.8	12.4
		8/27	23		124	9.9	7.5	12.0
2	McCormick Creek - 20 ft. upstream from mouth	8/25	20		111	11.3	7.8	13.5
		8/26	30	41.83	119	11.9	8.2	13.0
		8/27	122		122	11.0	7.6	11.9
3	Purdy Creek - above culvert at Highway 16	8/25	350		100	10.2	7.5	13.2
		8/26	74 est	163.90	289	10.5	8.6	14.1
		8/27	170		227	10.3	7.6	12.2
4	Burley Creek - above first riffle	8/25	250		95	10.5	7.6	12.5
		8/26	660 est	413.98	102	10.2	7.6	12.3
		8/27	430		541	10.1	7.5	12.8
5	Unnamed Creek - west shore across lagoon from willow tree	8/25	2		41,500	8.6	8.0	17.6
		8/26	5	3.27	41,300	10.7	8.2	17.3
		8/27	[3.5]*		---	----	---	----
6	Unnamed Creek - Goodrich Dr., down driveway (Boyd) to culvert, upstream side	8/25	65		42,500	8.5	8.0	16.5
		8/26	2,000	379.37	3,890	10.2	8.1	16.1
		8/27	420		661	10.3	7.5	12.4
7	Unnamed Creek - west shore 250 yards north of yellow house	8/25	430		130	9.3	7.8	----
		8/26	590	404.05	123	9.4	7.5	14.0
		8/27	260		19	9.8	7.6	12.3
8	Wauna Boat Ramp - 50 feet out, saltwater sampling	8/25	<1		43,600	8.6	8.0	16.2
		8/26	340 est	18.44	43,000	10.2	8.3	16.6
		8/27	30		45,200	8.2	8.1	----
9	Burley Lagoon - Inside spit at end closest to Wauna	8/25	12 est		42,200	8.1	8.0	----
		8/26	1	5.89	43,300	11.3	8.2	16.5
		8/27	17		45,300	9.5	8.2	16.2
10	Burley Lagoon - Just off point where oyster company is located	8/25	6 est		40,800	10.8	8.1	17.9
		8/26	1 est	4.48	43,500	10.0	8.2	16.8
		8/27	15 est		43,200	8.2	8.2	16.4
11	Burley Lagoon - west side, just offshore from multi-level green house	8/25	2 est		42,300	8.1	8.0	15.5
		8/26	44	12.46	44,700	10.4	8.3	16.5
		8/27	22		42,900	8.7	8.1	16.2
12	Burley Lagoon - east side, just offshore from brown house and A-frame	8/25	4 est		41,700	8.9	8.1	15.9
		8/26	3 est	6.69	43,600	10.7	8.3	17.0
		8/27	25		43,900	8.7	8.1	16.4
13	Burley Lagoon - south side of small islands	8/25	<1		41,600	8.7	8.1	16.0
		8/26	10 est	5.19	42,400	10.9	8.2	16.9
		8/27	14 est		45,100	9.1	8.2	16.0
14	Burley Lagoon - halfway between entrance neck to upper embayment	8/25	1 est		41,100	9.3	8.1	17.2
		8/26	2 est	4.48	41,600	10.6	8.3	16.9
		8/27	45		41,500	7.7	8.1	16.0
15	Burley Lagoon - halfway between widest point of upper embayment, used survey stakes as reference on west side	8/25	2 est		40,500	8.6	8.2	18.7
		8/26	6 est	9.99	41,300	11.2	8.3	17.0
		8/27	83 est		38,200	7.5	8.0	----
16	Burley Lagoon - largest piling in upper embayment	8/25	<1		39,300	10.2	8.3	19.6
		8/26	2 est	5.85	41,600	10.8	8.3	17.0
		8/27	100		28,600	8.2	7.9	15.0
17	Pearls by the Sea Restaurant - 20 feet offshore	8/27	6 est	6	46,900	9.0	8.1	16.4
[A]	Burley Lagoon - sediment sample 20 yds. off brown house and A-frame on east side	8/25	85 [MPN] sediment 13 est water		43,600	8.9	8.0	15.9
[B]	Burley Lagoon - sediment sample 20 yds off multi-level green house on west side	8/25	70 [MPN] sediment 2 est water		42,300	8.1	8.0	15.5
[C]	Burley Lagoon - sediment sample, west shore, red house with red float dock	8/25	0 [MPN] sediment <1 water		41,600	8.5	8.1	15.7
[D]	Burley Lagoon - sediment sample just off point where oyster company is located	8/25	85 [MPN] sediment 6 est water		40,800	10.8	8.1	17.9

[1] Median values are circled.

*Mean of two previous day samples; sampling was not accomplished on third day.

Table 2. Summary of data from Burley Creek and Purdy Creek Surveys (August 26, 1981).

Station Numbers & Description	FC	FS	FC:FS Ratio	D.O. (mg/L)	pH (S.U.)	Temp. (°C)	COD (mg/L)	BOD (mg/L)	NO_3-N (mg/L)	NO_2-N (mg/L)	NH_3-N (mg/L)	Total Phos. (mg/L)	O-PO_4-P (mg/L)
3-1 Purdy Creek - upper reaches at Burley - 011A1A Road	120	28	4.29	10.5	7.5	12.5	30	<2	.07	.01	.01	.03	<.01
3-2 Purdy Creek - upper middle reaches at Nelson Road	66	48	1.38	10.7	7.5	12.1	--	--	.07	<.01	.01	.03	<.01
3-3 Purdy Creek - middle reaches at Walnut-Bandix Road above confluence with Wikstein Creek	510	100	5.1	9.8	7.5	13.7	--	--	.07	<.01	.01	.03	<.01
3-A Wikstein Creek - before confluence at Walnut-Bandix Road	4	36	0.11	10.9	8.0	11.5	--	--	.02	<.01	<.01	.03	<.01
3-4 Purdy Creek - lower middle reaches at 160th	91	54	1.69	9.7	7.6	13.4	--	--	.07	<.01	<.01	.03	<.01
3-5 Purdy Creek - lower reaches - driveway off of Stevens Road	37	152	0.24	----	7.6	----	--	--	.08	<.01	.01	.02	<.01
3 Purdy Creek - at mouth	74	100	0.74	10.5	8.6	14.1	15	<2	.11	<.01	.03	.03	.01
4-1 Burley Creek - upper reaches at Mullenix Road	200	130	1.54	10.0	7.5	12.4	6	<2	.41	<.01	.02	.04	.03
4-2 Burley Creek - upper reaches at Holman Road	200	120	1.67	9.7	7.4	11.5	--	--	.30	<.01	.02	.04	.03
4-3 Burley Creek - middle reaches at 011A1A Road	240	150	1.60	10.5	7.7	11.8	--	--	.26	<.01	<.01	.04	.03
4-4 Burley Creek - lower middle reaches at Fenton Road	230	300	.77	10.5	7.8	12.1	--	--	.26	<.01	<.01	.06	.03
4-5 Burley Creek - lower reaches at Spruce Road	260	370	.70	10.5	7.7	12.1	--	--	.26	<.01	<.01	.06	.03
4 Burley Creek - at mouth	660	1400	.47	10.2	7.6	12.3	4	<2	.27	<.01	.01	.04	.03

Table 3. Fecal Coliform Results for Freshwater Streams Bordering Burley Lagoon. Samples Collected on August 25, 26, 27, 1980 survey.

Location	Number Samples	Geometric Mean[1]	Median Value	State Water Quality Standard (FC per 100 ml)	Percent Samples Exceeding Standard > 100 org/100 ml	Comments
Burley Creek	3	414	430	50	100%	Exceeds Standard
Purdy Creek	3	164	170	50	66%	Exceeds Standard
Hyde Creek	3	27.2	25	50	--	Within Standard
McCormick Creek	3	41.8	30	50	33%	Exceeds Standard
Unnamed Creeks						
Number 5	2	3.3	3.5[2]	50	--	Within Standard
Number 6	3	379.4	420	50	66%	Exceeds Standard
Number 7	3	404	430	50	100%	Exceeds Standard

[1]Geometric mean included for benefit of comparison to median (does not relate to standard).
[2]Only two days of sampling data available. This is the $\overline{X}$ of those values.

Table 3-A. Fecal Coliform Results for Marine Waters of Burley Lagoon. Samples Collected in August 25, 26, 27, 1980 Survey.

Location	Number Samples	Geometric Mean	Median Value	State Water Quality Standard (FC per 100 ml)	Percent Samples Exceeding Standard > 43 org/100 ml	Comments
Burley Lagoon	29	5.92	6	14	13%	Exceeds Standard

Table 5. Fecal Coliform Stream Loads Estimates for Burley Lagoon from Freshwater and Henderson Bay Sources. Samples Collected during August 25, 26, 27, 1980 Survey.

Creek Name	Station Number	Stream Flow	FC/100 ml	Mean Value FC per 100 ml	Fecal Coliform Total Load FC per day	Percent of Stream Loading for Fecal Coliform Bacteria
Hyde Creek	1	.77 cfs	25 35 23	[27.7]	3.32×10^{9}	1.8%
McCormick Creek	2	.56 cfs	20 30 71	[40.3]	3.51×10^{9}	1.9%
Purdy Creek	3	1.90 cfs	320 74 170	[198.0]	5.85×10^{10}	32%
Burley Creek	4	15.91 cfs	250 660 430	[446.7]	1.10×10^{11}	61%
Unnamed Creek	5	.50 cfs	2 5	[3.5]	2.72×10^{8}	.2%
Unnamed Creek	6	.04 cfs	65 2,000 420	[828.3]	5.24×10^{9}	2.9%
Unnamed Creek	7	.21 cfs	44 2 22	[22.7]	7.61×10^{8}	.5%
Henderson Bay	17	4400.00 cfs	5	[5]	5.4×10^{11}	

Table 6. Accumulation Ratios of Pacific Oysters (from Vasconselos, *et al*., 1969).

Date	Temperature Range (°C) Mean	Temperature Range (°C) Range	Total Precipitation (inches)	Ratio: [FC per 100 gr/FC per 100 ml] Oysters
November 1965	9.7	8.7 - 10.6	7.57	13
January 1966	7.6	7.3 - 7.9	10.61	4
February 1966	7.5	7.0 - 8.0	2.97	24
March 1966	6.5	4.0 - 9.0	8.38	88
July 1966	19.0	15.0 - 23.1	0.88	13
August 1966	19.8	16.7 - 22.8	0.35	12
October 1966	10.0	8.6 - 11.5	3.65	6
November 1966	10.3	9.8 - 10.8	7.35	6